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Measurement of Geomagnetic and Atmospheric Noise at a Remote Site

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PREFACE

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13. ABSTRACT *(Maximum 200 words)*

A magnetic field observatory has been established at Fisher's Island, NY, where the geomagnetic and atmospheric noise in the frequency band from 0.5 to 30 Hz is measured continuously. The primary sensors are an orthogonal pair of 2-m air-core loops, whose sensitivity makes them among the world's quietest at 70 fT/√Hz. These loops are free of mechanical interference from natural forces (such as wind and waves), having been designed so that their electrical band is below the first mechanical resonance at 37 Hz. After transmission directly over an existing microwave link to a laboratory in New London, CT, the data are plotted on a frequency-versus-time spectrograph for quick-look analysis while they are simultaneously digitized, Fourier transformed, averaged, and stored on magnetic disk. Averaged plots of magnetic field strength over various time cycles have been made. General observations show that the atmospheric noise is highest in the summer, corresponding to increased electrical activity in the tropics. Averaged Schumann resonances have also been plotted over a 1-year timeframe to show characteristic seasonal effects.

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INTRODUCTION

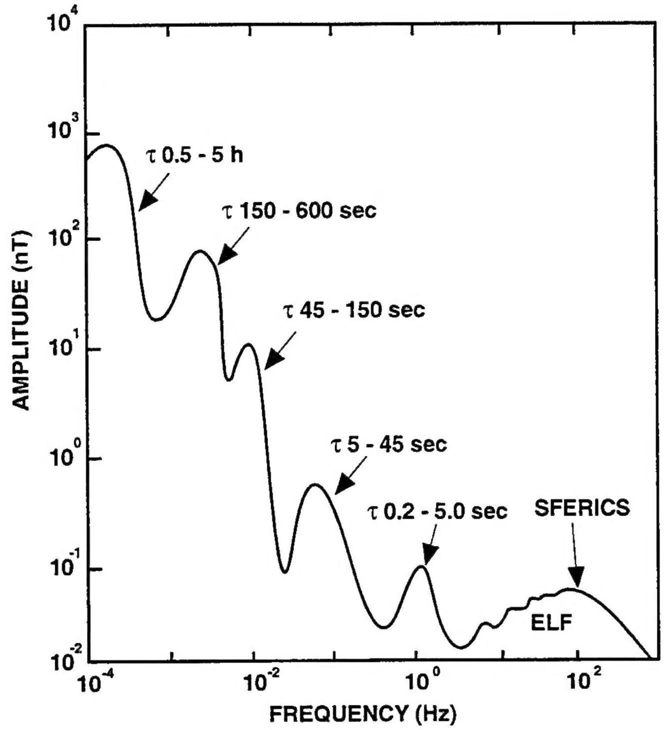
The study of the earth's geomagnetic and atmospheric noise has been the subject of much interest throughout the history of radio communications. Most of this attention has been directed to the area of communication frequencies, with the frequency band from 0.5 to 30 Hz being largely ignored because no manmade communications occur in this range. This band is a transition region between the Pc1 micropulsations of the ionosphere (0.2 to 5 Hz) and the low end of the atmospheric noise band characterized by the first Schumann resonance at 7.8 Hz.* A minimum in the background noise field is believed to exist between 1 and 10 Hz, but little evidence is available in the literature to support this view. Early field work has been reported by Maxwell and Stone,[1] Campbell,[2] and Fraser-Smith and Buxton.[3] More recent data, documented by Bannister et al.,[4] have been collected from a low-frequency station located on Fisher's Island, NY. The reported measurements, made with magnetic-type sensors, present evidence for a relative minimum in the noise field from 1 to 7 Hz. Figure 1 (from reference 2) shows a typical magnetic spectrum from 0.1 mHz to 1 kHz; a similar spectrum is shown by Forbes.[5] Both figures indicate evidence of the presumed minimum in the magnetic spectrum from 1 to 10 Hz.

It is clear from the magnetic spectra that the earth's natural noise field varies by more than five orders of magnitude (100 dB) from 0.1 mHz to 1 kHz. The wide dynamic range imposed by such a noise structure has forced investigators to build equipment suitable for each of the various bands of interest. As a result, little is known about the band below the sferics (see figure 1), but above Pc1.

EQUIPMENT AND EXPERIMENTAL TECHNIQUE

Although there are various types of magnetic antennas discussed in the literature, the two considered for this study are air-core and portable magnetic-core loops. While air-core loops are not affected by calibration errors, they must be relatively large to achieve the required sensitivity in the band of interest. The air-core loops used here are 2 m in diameter, have a 1397-m^2 turns area product, a sensitivity of 70.0 fT/√Hz, and an equivalent limiting noise field of 56 fT/√Hz at 1 Hz. However, these loops are so large that they must be buried to avoid contaminating the data with motion noise caused by wind excitation and the regular pounding of the beach from wave

*It should be noted that magnetic variations (which are classified by their regularity and period) are commonly referred to as pulsations or ultralow frequency (ULF) waves, with the shortest period variations of a regular nature designated as Pc and the irregular pulsations as Pi. Each designation has a specific period associated with it; for example, Pc1 occurs from 0.2 to 5 seconds.



FROM REFERENCE 2

Figure 1. Spectrum of the Earth's Magnetic Field (0.1 mHz to 1 kHz)

action. The wind is particularly problematical because it can directly buffet the loops, as well as shake the ground through nearby trees. These effects are minimized by designing the electrical band to be below the first mechanical resonance of the loop. The first mechanical resonance was designed to be at 37 Hz, which is well above the band of interest. Figure 2 shows two partially buried orthogonal air-core loops installed at Fisher's Island.

The portable loops designed and built for this investigation are 0.4-m-long solenoidal coils wound on a Plexiglas tube that is 0.15 m in diameter. To increase the effective turns area product, the coil is loaded with a 2.4-m-long laminated magnetic core having an average relative permeability (μ_r) of 625, which results in a turns area product of 636 m^2. The length-to-diameter ratio is kept large to minimize leakage inductance and to avoid calibration problems with the loop. Because of the magnetic material used in the antennas, this approach is not often used to measure magnetic fields. However, in this case, it is the only way to achieve the necessary sensitivity (130 fT/√Hz) while maintaining the portability of the sensor. Figure 3 is a diagram of the portable magnetic antenna.

Data from the remote site were transmitted directly to the laboratory at NUWC Detachment New London for further analysis and processing. Figure 4 shows the geomagnetic and atmospheric noise measurement system in block diagram form. As can be seen in the figure, each loop antenna output signal is amplified and conditioned by a 30-Hz lowpass filter and is input to its own voltage-controlled oscillator (VCO) subcarrier. The two VCOs are summed and

Figure 2. The 2-m Air-Core Loops Installed at Fisher's Island, NY

the composite frequency division multiplex signal modulates the main ultrahigh-frequency (UHF) carrier. The UHF signal is then transmitted via a line-of-sight dish antenna system from Fisher's Island to the laboratory. Both the carrier and subcarrier signals are then demodulated and the two channels of recovered baseband analog data are routed to a line scan recorder (0 to 30 Hz) for quick-look analysis. The data are also digitized and transferred to a personal computer for fast Fourier transform (FFT) and subsequent analysis. The FFT data are stored on magnetic disk for further study.

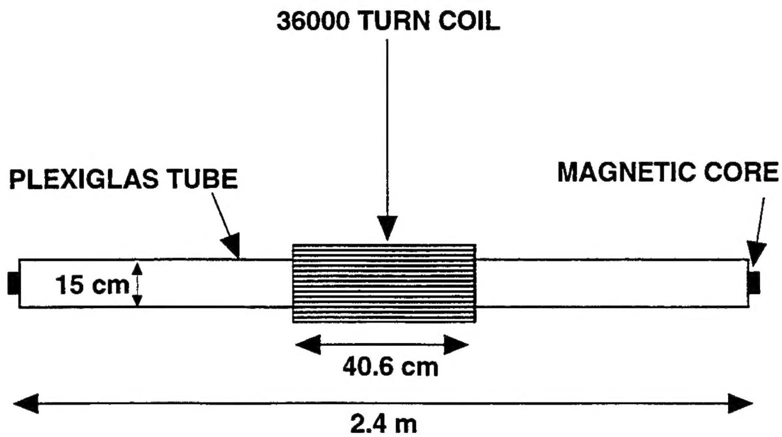


Figure 3. Portable Magnetic-Core Antenna

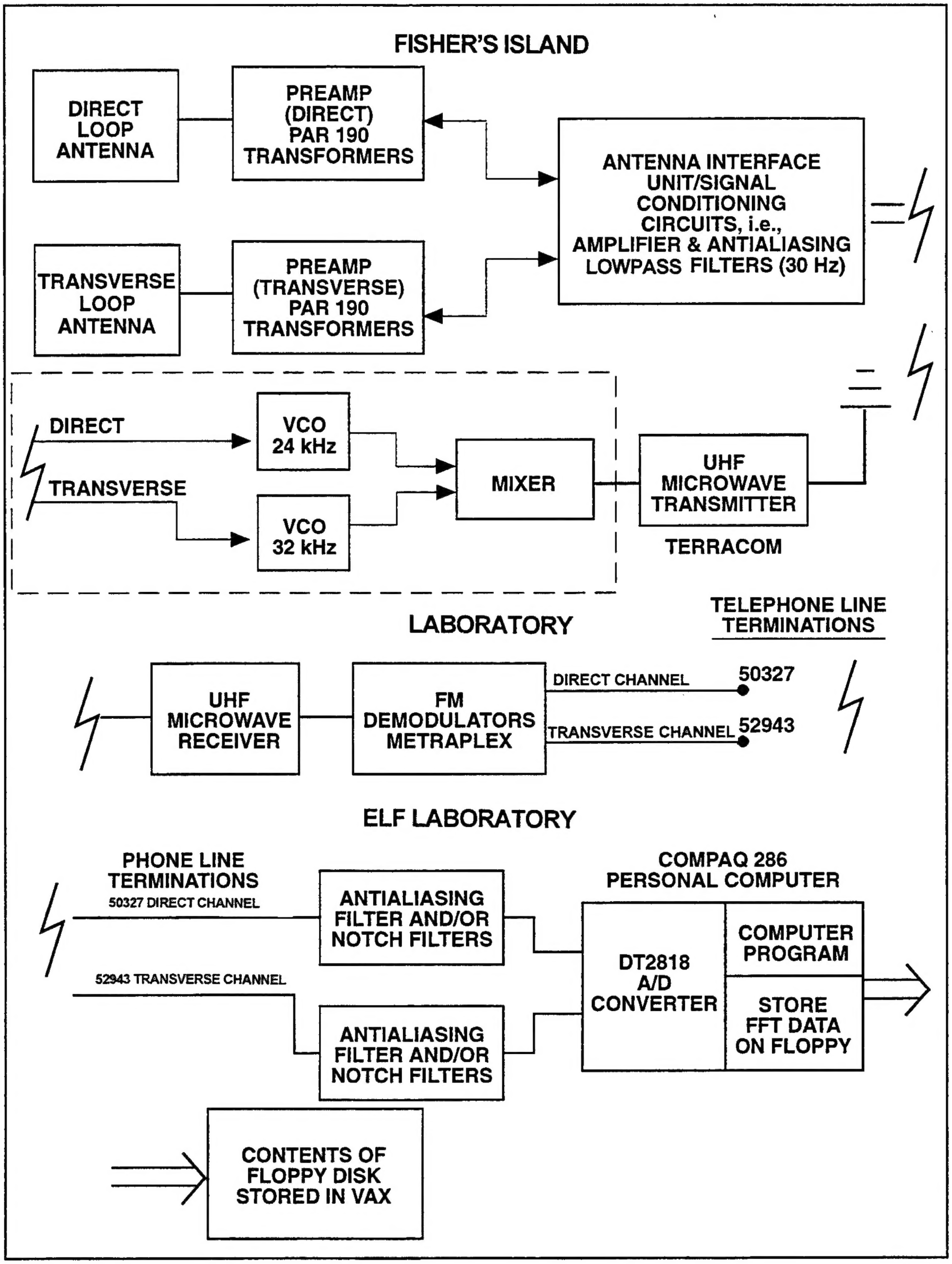


Figure 4. Block Diagram Showing Equipment for the Noise-Measuring System

RESULTS

To facilitate analysis, the 24-hour measurement day is divided into six 4-hour time periods. The spectral data are averaged over each of these periods to obtain a composite look at the noise field in any time period. Typically, the data are summarized on a month-to-month basis. Figure 5 shows rms geomagnetic plots of the maximum and minimum noise spectra data averaged over July and December 1994 during the 0000-0400 and 1200-1600 hour time periods for the two orthogonal air-core antennas (oriented 90° to each other). The average noise of these antennas appears to be isotropic; i.e., there is no directional bias to the long-term-averaged noise. The curves also show that the maximum spread of the noise averaged over 1 year is approximately 10 dB (0.5-5 Hz). This is an important statistical parameter needed for performance predictions of any detection system operating in this band. Also note that both the high and low spectra show evidence of a minimum in the noise field between 1 and 7 Hz.

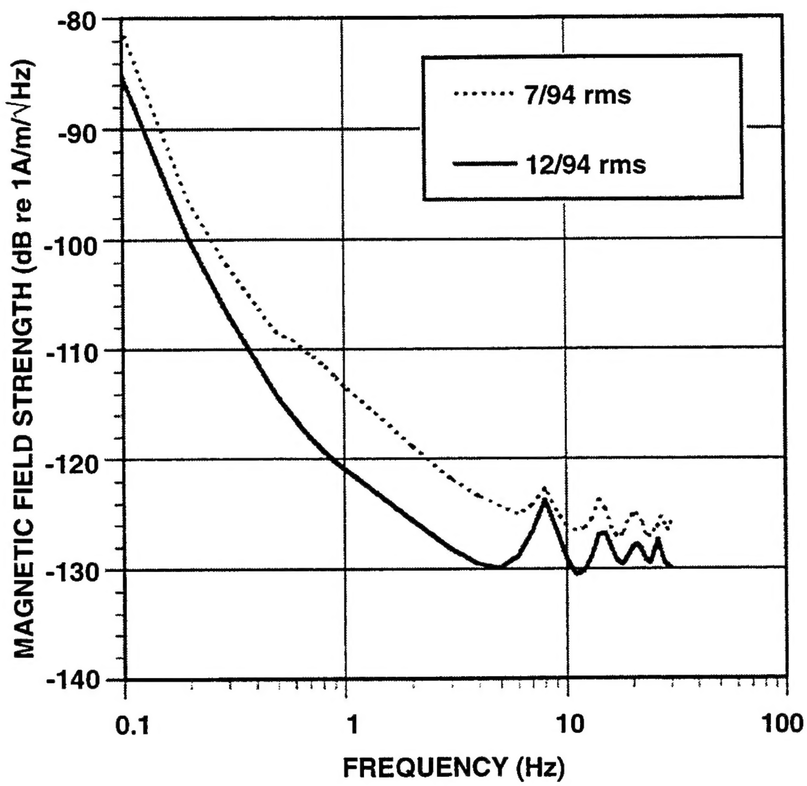


Figure 5. Average rms Magnetic Noise Spectra for July and December 1994

An important feature of the magnetic noise is the set of peaks clustered near 10 Hz. These harmonics are known as the Schumann resonances[6] and represent the lowest transverse electromagnetic (TEM) mode supported by the earth-ionosphere cavity. A simple calculation based on the average radius of the earth r ($r = r_0 + h/2$, where h is the average ionospheric

height of the F1 layer and r_0 is the earth's radius) predicts that the longitudinal resonance modes occur at $f_n = cn / 2\pi r$, where $n = 1, 2, 3, \cdots$, and c is the propagation velocity 3.0 x 10^8 m/s. For the first mode, $n = 1$ and $f_1 = 7.5\,\text{Hz}$. Figure 6 shows the monthly averaged f_1, f_2, and f_3 Schumann resonances measured from July 1994 to May 1995. The yearly cyclical nature of the magnetic activity of the ionosphere is revealed in this plot. The data indicate an increase in the amplitude of the magnetic field during the summer months, with the maximum occurring during July. This increase in amplitude can be associated with increased electrical activity in the ionosphere that normally accompanies summer in the Northern Hemisphere. A minimum of magnetic field strength is shown during the winter months, with the lowest level observed in December. The correlation with decreased electrical activity is evident. All three longitudinal resonance frequencies follow this trend.

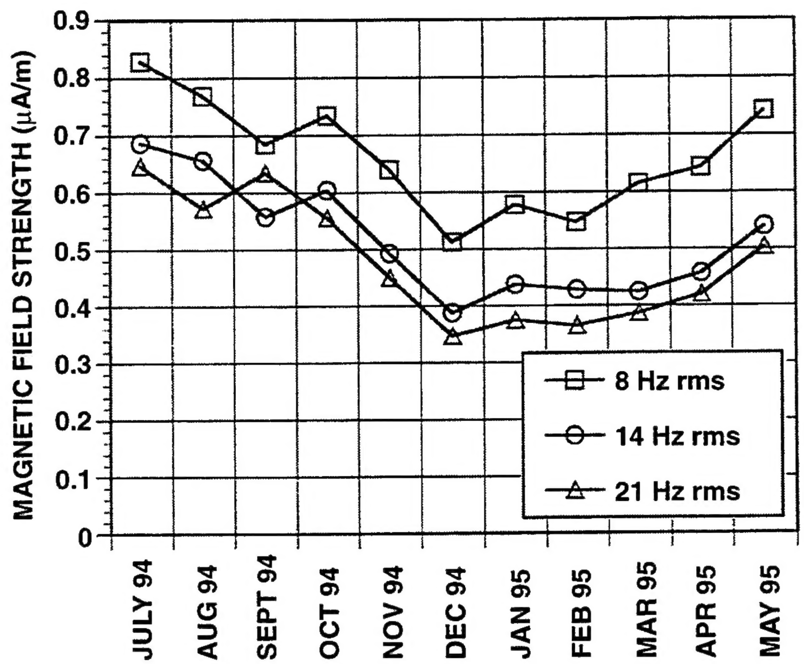


Figure 6. Monthly Averaged Earth-Ionosphere Longitudinal Resonances (Modes for n = 1, 2, and 3)

Data measured by Polk[7] in the 1970s and more recent results published by Williams[8] in 1992 indicate that the Schumann resonance amplitude can indicate trends in global temperature variations.

In 1994, discoveries by Kerr[9-11] in atmospheric research indicated the existence of complex lightning phenomena between the upper cloud layers of thunderstorms and the ionosphere. Designated as Blue Jets and Red Sprites, these exotic lightning forms were visually observed. Fishman,[12] also in 1994, reported on correlations between such visually observed forms of

lightning and earth-originated gamma ray bursts detected by satellite from the Compton Gamma Ray Observatory. In 1995, the Marshall Space Flight Center granted the authors of this report access to these satellite data[13] (where observed gamma ray atmospheric bursts are noted by event, trigger time, and satellite location over the earth). A search of the Fisher's Island magnetic data, which are line scanned and time dated in real time (local or alpha time (AT)), revealed possible correlations with the Compton satellite data. In table 1, a summary of all the data reviewed so far, the "Event" number (as recorded on the Compton satellite) is followed by its date (year-month-day) and universal time (UT) reference in seconds. UT time is then converted to equivalent AT (Eastern Standard Time) at Fisher's Island, NY. Corresponding ULF events are noted in the table under Fisher's Island (FI) time with an event description. Irregular frequency bursts in the 0.5- to 2-sec band at Fisher's Island could only be reconstructed into broad time frames where events were observed in the line scan data. In 1995, Williams[14] reported on the possible correlation of exotic lightening with extremely low-frequency (ELF) disturbances.

A method has been developed that allows for the reliable calibration of the portable magnetic-core loops by using the large air-core loops as a reference. The air-core loops were originally calibrated with continuous wave transmissions from the Wisconsin ELF transmitter. (This explains the use of the nomenclature *direct* and *transverse* on figure 4—the direct loop antenna is oriented to point toward the Wisconsin ELF transmitter and the transverse loop antenna is orthogonal to it.) The field from a distant source (i.e., the ELF transmitting antenna) can be computed very accurately on the surface of the earth, and this known field strength can be used as a reference to compute antenna gain. The output of the calibrated antenna can then be compared to the output of other nearby antennas operating in the same frequency range.

Table 1. Compton Gamma Ray Observations Correlated with Fisher's Island Station Observations

Compton Satellite Events			**ULF Events at Fisher's Island**	
Event	**Date, UT (sec)**	**AT (hr)**	**FI Time**	**Description**
3314	941208, 47312	8.14	0000-0900	0 to 2 Hz Irregular
3331	941209, 75401	15.94	1000-1500	0 to 1 Hz Irregular
3470	950316, 34736	4.65	0200-0300	1 Hz Irregular
3478	950321, 30118	3.37	0530-0630	1 Hz Irregular

CONCLUSIONS

It has been shown that an earth observatory located at a remote site (Fisher's Island, NY) can be operated via a microwave link and a stand-alone personal computer. This technique allows continuous monitoring of the earth's magnetic field fluctuations in the 0.5- to 30-Hz frequency band with minimum human involvement and therefore minimum cost. The data analyzed to date indicate that the monthly averaged Schumann resonances exhibit a cyclical pattern that relates to seasonal changes in the northern latitudes. A theory advanced by several investigators correlates this cyclical pattern with increased lightening activity in the Northern Hemisphere during the summer months. A possible correlation of large-scale disturbances in the ionosphere (0.5- to 2-sec periods) with gamma ray bursts from the earth as detected by the Compton Gamma Ray Observatory has also been demonstrated. Because gamma ray bursts from the earth were not discovered until 1994, there is no theory yet available to explain the recent observations. The Compton satellite sensor is currently being reconfigured to increase its sensitivity in the earth-looking mode. Techniques for performing the line scan function digitally are available but have not yet been implemented.

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